Strategic Knowledge Gap	Narrative (2012)	Enabling or Enhancing	Retired	Exploration Science or Technology	Messurements or Mission needed to retire SKG	Notes 2016
II-A-1 Solar Activity/solar event prediction	Define active regions that are potential SEP/CME sites over the 1/2 of a solar rotation (i.e., for use as a space weather 'watch' notification system	Enabling for both 28 day mission and for longer stays.	No	Science/Technology	Joint SMD Heliophysics and HEOMD mission to L5. Have onboard A) EUV imaging telescope to identify active regions. B) White light coronagraph to identify Earth-directed CMEs	This monitoring spacecraft acts as a sentinel to establish locations and intensity of active regions on the sun. The active region may not launch a mission-altering SEP, but is a possible source. Knowing the locations provides explorers with advance notice that conditions could change. Observations of these active regions provides an analogous 'watch' condition of severe meteorological weather.
II-A-2 SEP warning system	Provide an immediate alert system for an impending SEP event (i.e., a warning system)	Enabling for both 28 day mission and for longer stays.	No	Science & Technology	Landed suprathermal ion and electron detection to provide SEP warning to explorers. On lunar surface to examine any secondary radiation effects.	If an active region is magnetically connected to the Earth-moon system, and does flare, explores only have minutes before the most energetic solar particles can arrive. A warning system is thus needed so the explorers can seek shelter. As a hazard alert system, the IDPU would contain algorithms to identify the hazard based on the precursor-period observations (identification of a signature precursor is a needed science investigation). HEOMD should also consider the development of using other solar data, like solar radio emissions, into identifying hazards. This added element has not been considered but could provide added information in the hazard identification. SEP information can also be obtained from orbital spacecraft, but will not have surface effects. L1-located Advanced Composition Explorer (ACE) launched in 1997 is suggested to be replaced with next gen system (e.g., the Interstellar Mapping and Acceleration Probe).
II-B-1 Radiation environment at the lunar surface (Model)	Model primary and secondary radiation components; confirm secondary models by measuring the affect of appropriate, comprehensive radiation sources at terrestrial laboratories (e.g. Brookhaven) on detectors such as TPCCs and lunar soil/simulant.	Enhancing	Partial/Yes	Science	Consistent modeling effort	The LRO CRaTER team is currently modeling secondary radiation effects from incidence GCRs. See Looper at al., 2013, Space Weather, 11, p142. However, the modeling is tied to continued LRO funding and has value independent of any one mission. Much of the work done to date involves correlation between GCR fluxes and sunspot number. However, operational models are not physics-based. Additional work is needed to develop physics-based models that derive Linear Energy Transfer from GCR modulation. Such models are currently in work, but depend on stable funding to develop, complete and validate with CRaTER data.
II-B-2 Radiation environment at the lunar surface (Measurement)	Directly measurement primary and albedo/ secondary radiation on the lunar surface for Galactic Cosmic Rays and solar-derived radiation sources; GCRs and solar sources should be measured over a minimum of one solar cycle	Enabling for both short and long duration missions	Partial/Yes	Science	Place a Lineal energy transfer (LET) spectrometer system on the surface. . Measures the energy deposited in a material of given thickness during the particles passage. LRO/CRaTER is an example of this type of instrument, but added development can enhance the capability to include the destructive neutrons.	LRO/CRaTER has developed albedo maps for secondary protons[Wilson et al, 2012, JGR, 117, E00H23; Spence et al., Space weather 11 643, 2013] which represent the kind of product to be created. The next generation CRaTER is suggested to also monitor secondary neutrons should be flown to assess both primary and secondary radiation sources. Such measurements can be obtained from low-altitude orbit.
II-B-3 Radiation shielding effects of lunar material (Model)	Model and measure the radiation shielding properties of lunar soil samples and/or simulant.	Enhancing	Partial/Yes	Science	Consistent modeling effort	The LRO CRaTER team is currently modeling shielding effects from high energy GCR, focusing on the effect of hydrated layers. However, the modeling is tied to continued LRO funding and has value independent of any one mission.

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II-B-4 Radiation shielding effects of lunar material (Measurement)	Landed robotic missions needed to directly measurement radiation shielding properties of lunar soil by covering detector arrays with variable depths and densities of regolith; detector arrays must have sufficient sensitivity and variation in particle energy to cover both the expected population of solar-derived radiation and Galactic Cosmic Rays.	Enhancing for a 28 day mission, possibly enabling for a long stay.	No	Science	LET spectrometer with Thin/Thick Silicon detectors between predesignated material like Tissue Equivalent Plastic (TEP), lunar regolith, even microbiotic material.	Zeitlin et al., Space Weather, 11, 284, 2013 have quantified the effects of shielding on the lunar surface based on CRaTER observations
II-C-1 Biological effects of lunar dust (Earth-based testing)	Production of relevant lunar soil simulants. Measure reactivity of archived Apollo samples/lunar soil simulants. Measurements of the most pristine samples could yield the best data	Enhancing for a 28 day mission, enabling for a long stay.	Partial/Yes	Science	Obtain particle size distribution, microscopy, and passivation/reactivity.	There are broad array of possible reacting agents. Any flight instrument will likely have to rely heavily on Earth-based testing to identify the reacting agents to be tested in situ. These reacting agents of the dust may be chemical or physical (small, sharp). If the agent is chemical, then reactivity tests, including the effects of water on the passivity, should be performed. The SSERVI RISE4 team has a component performing such tests on grain reactivity.
II-C-2 Biological effects of lunar dust (In situ testing)	Test reactivity dust in the lunar environment.	Enhancing for a 28 day mission, enabling for a long stay.	No	Science	In situ obtain: A) Particle size distribution and dust shape morphology studies of the smallest particulates, from varied sample sites B) Insitu grain-clump adhesion strength and clump size distributions C) Passivation experiment to determine grain reactivity as transported from intrinsic environment into normal atmosphere	If the reacting agent is chemical, then reactivity tests, including the effects of water on the passivity, should be examined. If the agent is physical, then detailed microscopic examination of the finest grains found in situ should be made. Small grain electrostatics/cohesion may be tested in the plasma/electrical environment to determine if they adhere to form larger less invasive grains, and such a test can only be performed in the actual environmental setting.
II-D How to maintain peak human health and	Research the fundamental biological and physiological					This list below is a subset of the larger gap study done by the Human Research Program. The emphasis herein is on those overlapping SKGs that can be performed in robotic

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II-D-1 Radiation and Humans	Radiation Themed: A) Acute and late nervous system effects from radiation exposure , B) Acute radiation syndromes from SEPs , C) Radiation Carcinogenesis	Enhancing for a 28 day mission, enabling for a long stay.	no	Science	Robotic precursor program can contribute LET Spectrometer (like that described above) which provides environmental information that feeds forward to address tissue damage either by experiment or model.	HRP program covers elements of this but measurements obtained by robotic precursor feeds directly forward to the HRP efforts. More elaborate experiments should be devised. Experience with humans exposed to high LET is limited to a) proton therapy for focal treatment of cancer, b) modest exposures in orbital missions, C) transit to the Moon, d) surface missions on the Moon, and e) modeled exposures in experimental animals, tissues and cells are conducted a BNL and other facilities. Very little data has resulted from the therapy protocols save for the effect on the tumor. Analysis of exposure data from orbital missions along with computational modeling has resulted in setting the exposure limit to that putatively associate with a 3% lifetime risk for cancer. The time spent in 'free space' during transit can be problematic for longer missions, e.g., Mars transit. Planetary surfaces afford some diminution in exposure. There is concern regarding the nature and radiation flux from the albedo. Mission planning will help in decreasing the risk. For example, at solar max there is a decrease in GCR with a higher risk for acute exposure from solar storm energetic particles form CME's. With the appropriate alert systems in place and mission planning, the crew could be shielded during these solar events. In contrast the GCR is of a constant unrelenting low flux There are specific health risks that remain of concern: (a) Cognition may be affected during long missions such as lunar colonization and Mars habitation, (b) In these scenarios we are concerned about acute phase exposures and chronic exposures such as GCR and even multiple SPE's. (c) Duration of the mission will likely determine the number of risks and the mitigations strategies. (d) The central and peripheral nervous system, gastrointestinal system, the cardiovascular system, and possibly immunity may be significantly affected Summary: In addition to the earth based research in progress, there will need to be a robust research program conducted in transit and planetary environments to assess toxicity, mutagenicity, factors that determine susceptibility as well as tolerance to radiation, and the role of duration of exposure to radiation in maintaining human health.
II-D-2 Virus and Humans	Virus themed: D) Alteration in host-microorganism interactions	Enhancing for a 28 day mission, enabling for a long stay.	No	Science	The direct effect can be addressed in robotic missions wherein an automated system containing cells with viruses in latency have a process system that can assess production of free virus by cells in vitro. Such a system may be telemetrically operated and the data returned in real time. Also, the system can be designed to be self-sterilizing so as not to introduce viable organisms to the planetary environment.	Decreased immunities and/or increased virulence needs to be examined in situ. The prospect of problems with viruses while on a planetary surface mission is most likely going to be with radiation of latent viruses in humans. The only viruses we plan to engage are those brought by humans or carried on rovers and equipment. The viruses carried on hardware can be minimized by good practices. Those brought by humans are basically in two categories: 1) latent viruses, and 2) communicable disease causing. The latter is mitigated by clinical exam and preflight quarantine. It is the latent virus that can be reactive during space flight that could be a problem. It is not known if reactivation is caused by a decline in immunity or if it is a direct effect of the space environment, e.g., microgravity, radiation, etc.
II-D-3 Dust and Humans	Dust Themed: E) Biological consequences of exposure to dust and volatiles	Enhancing for a 28 day mission, enabling for a long stay.	No	Science	Robotic precursor program can contribute particle size distribution instruments and passivation experiment. See above.	These measurements can then feed forward to SSERVI and HPR efforts to simulate the human reaction to activated dust. The effect of dusts on human health has an extensive history in mining and manufacturing. The nature of the dusts on the Moon and on Mars is substantially different from those naturally occurring on Earth. The exposures are basically three types 1) inhaled, 2) ingested, and 3) surface contact. The biology of dusts is determined by 1) composition, 2) particle size, 3) structure (crystalline or amorphous), and 4) dose and duration of exposure. The effect of lunar dust on humans is based on anecdotal experience. Based on the Apollo missions, it is likely at its worst, an irritant. Using regolith simulants of the Moon in rats, the permissible exposures an currently set at 1.0 to 1.2 mg/m3. The simulants are usually quartz and/or TiO_2. Robotic missions to these surfaces should include toxicity and mutagenicity analyses in reference cell based systems to serve as a temporary benchmark for setting standards for humans occupying these environments for extended periods of time. Presently the risks associated with dust are being recast such that the emphasis will be on model living systems.

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II-D-4 Robot and Computer Compatability	Compatibility themed: F) Inadequate design of human/robotic integration, G) Inadequate human/computer interactions	Enhancing for a 28 day mission, enabling for a long stay.	No	Science	Adaptable system should be tested in robotic precursor program.	HRP developing systems but they could be tested as part of precursor robotic mission.